Field Emission Vacuum Electronic Devices for Operation above 500 degrees Celsius

Completed Technology Project (2017 - 2020)

Project Introduction

Objective: Boeing is teaming on this proposed project with the Nanofabrication Group (Prof. Axel Scherer) at The California Institute of Technology (Caltech). The Boeing-Caltech team is proposing to: (1) demonstrate Nanotriode devices based on Field Emission Vacuum (FEV) Electronics Technology; (2) design and fabricate small integrated circuit (oscillator for frequencies corresponding to S-band, 2 GHz); (3) verify the operation of devices and oscillator circuit at 500 C in vacuum, for over 1,500 hours (60 days). We also propose to monitor the performance parameters of the FEV devices and the oscillator circuit over temperature and operation time, to identify the main reliability mechanisms. Technical Background: Most semiconductor devices operate up to 250 C. Recent advances in carbide and nitride semiconductors hold promise for higher temperatures, yet are associated with high R&D costs. The well-established technology of microwave vacuum tubes is dominant for 500 degC, yet its dimensions limit severely the complexity of circuits. There is need for a technology with the simplicity of vacuum tubes and with micron sizes. The Nanofabrication Group at Caltech has developed, fabricated, and demonstrated, under Boeing funding, FEV nano-triodes in silicon with tungsten metallization. These robust devices developed at Caltech are fabricated using simple lithography process that yields stable, reproducible sub-50nm gaps between emitter, collector and gate. Heating the device to 500 degC in vacuum is compatible with the device operation, since they are not susceptible to traditional semiconductor limitations of carrier leakage, temperature dependence, and crystal imperfections. These results demonstrate that FEV devices can operate successfully for over 1,500 hours, at 500 C ambient temperatures. Technical Approach of Proposed Effort: We propose to develop and fabricate FEV devices and an oscillator circuit for 2 GHz (S-band). The implementation will be complemented by theoretical/simulation analysis of the path to X-band. The expertise and facilities developed at Caltech during the Boeing-funded R&D period will be leveraged for this proposal: nano-scale patterning; etching; oxide growth; metal deposition of tungsten. Tests for operation at high temperatures are performed with local heating (with temperature control) inside a customized small vacuum chamber, on a simplified packaging/substrate. Packaging development for extended operation is outside the scope of this proposal. Our proposed effort also includes: (1) development of device model for HSpice circuit simulations; and (2) simulation using first-principles (atomic-level) modeling tools, of metal migration for tungsten and derivatives (such as thoriated tungsten) at high temperature. Team, Capabilities, and Leverage: Our team is led by experts in RF Electronics and Electronics for Extreme Environments in the SSED (Solid State Electronics Development) group at Boeing Research & Technology, in collaboration with Prof. Axel Scherer and graduate students at Caltech. Boeing and Caltech have state-of-the art facilities for design and fabrication, augmented by customized setup for testing of FEV devices at high temperatures. Relevance: Supports the Planetary Science Decadal Survey: In Vision and Voyages for Planetary Science in the Decade 2013-2022, Chapter 5 states “Venus and Mercury, and

Field Emission Vacuum Electronic Devices for Operation above 500 degrees Celsius

Table of Contents

Organizational Responsibility

Responsible Mission Directorate:

Science Mission Directorate (SMD)

Responsible Program:

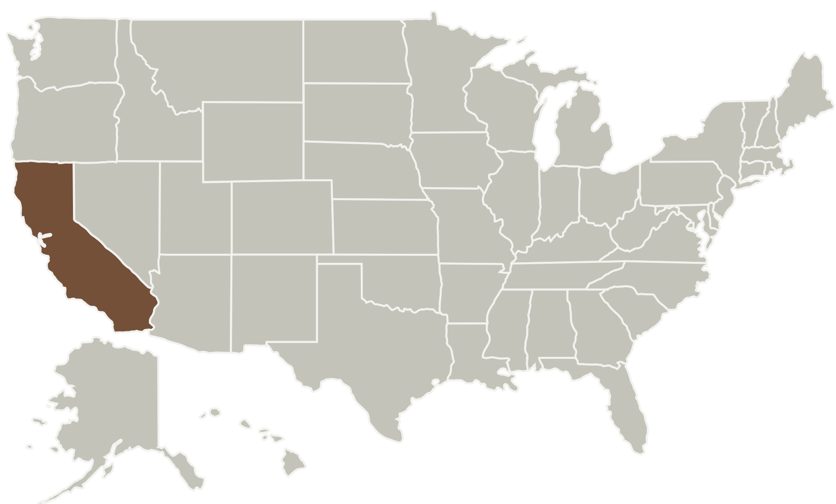
Hot Operating Temperature Technology

to a lesser extent the Moon, represent extreme thermal environments that will stress spacecraft capabilities. High-temperature survivability technologies such as new materials, batteries, electronics, and possibly cooled chambers will enable long-term in situ missions.” Consequently, NASA Venus Exploration Analysis Group (VEXAG) published a Venus Technology Plan (May 2014) which calls for “Development of high-temperature electronics, sensors and the thermo-electric power sources designed for operating in the Venus ambient would be enabling for future missions.”

Anticipated Benefits

In Vision and Voyages for Planetary Science in the Decade 2013-2022, Chapter 5, “The Inner Planets” states that “Venus and Mercury, and to a lesser extent the Moon, represent extreme thermal environments that will stress spacecraft capabilities. High-temperature survivability technologies for the surface of Venus and Mercury are addressed by our project.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
The Boeing Company(Boeing)	Supporting Organization	Industry	Chicago, Illinois

Project Management

Program Director:

Carolyn R Mercer

Program Manager:

Quang-viet Nguyen

Principal Investigator:

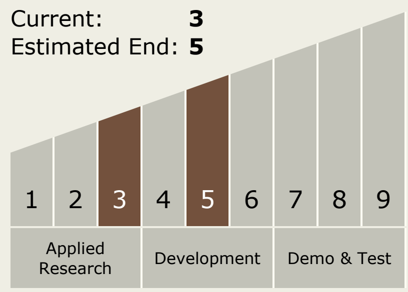
Leora Peltz

Co-Investigators:

Alan R Keith
William M Jones
William J Rockwood
Axel Scherer
Robert V Frampton

Technology Maturity (TRL)

Start: **3**
Current: **3**
Estimated End: **5**



Technology Areas

Primary:

- TX02 Flight Computing and Avionics
  - └ TX02.1 Avionics Component Technologies

Continued on following page.

Primary U.S. Work Locations

California

Technology Areas *(cont.)*

└ TX02.1.6 Radiation Hardened ASIC Technologies

Target Destination

Others Inside the Solar System